

FERMI/HAWC SYNERGIES

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WIDE FIELD, HIGH DUTY CYCLE INSTRUMENTS

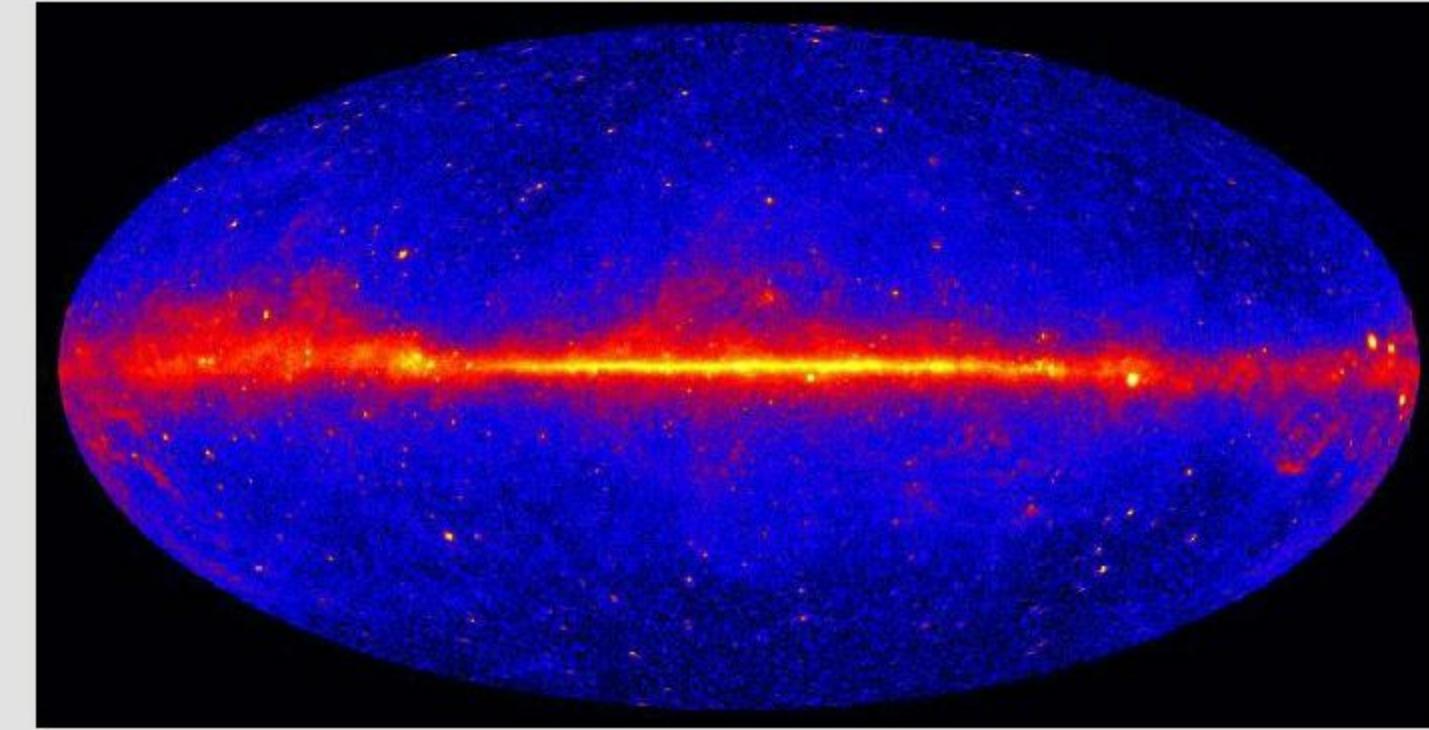
- Synergies:
 - Catalogs (population studies)
 - Transients/variability
 - Extended sources & diffuse emission (covered by Petra)

Instrument	Instantaneous FOV	cumulative FOV
Fermi/GBM	~75% of the sky	100% in 3 hours
Fermi/LAT	~20% of the sky	100% in 3 hours
HAWC	~15% of the sky	75% in 24 hours

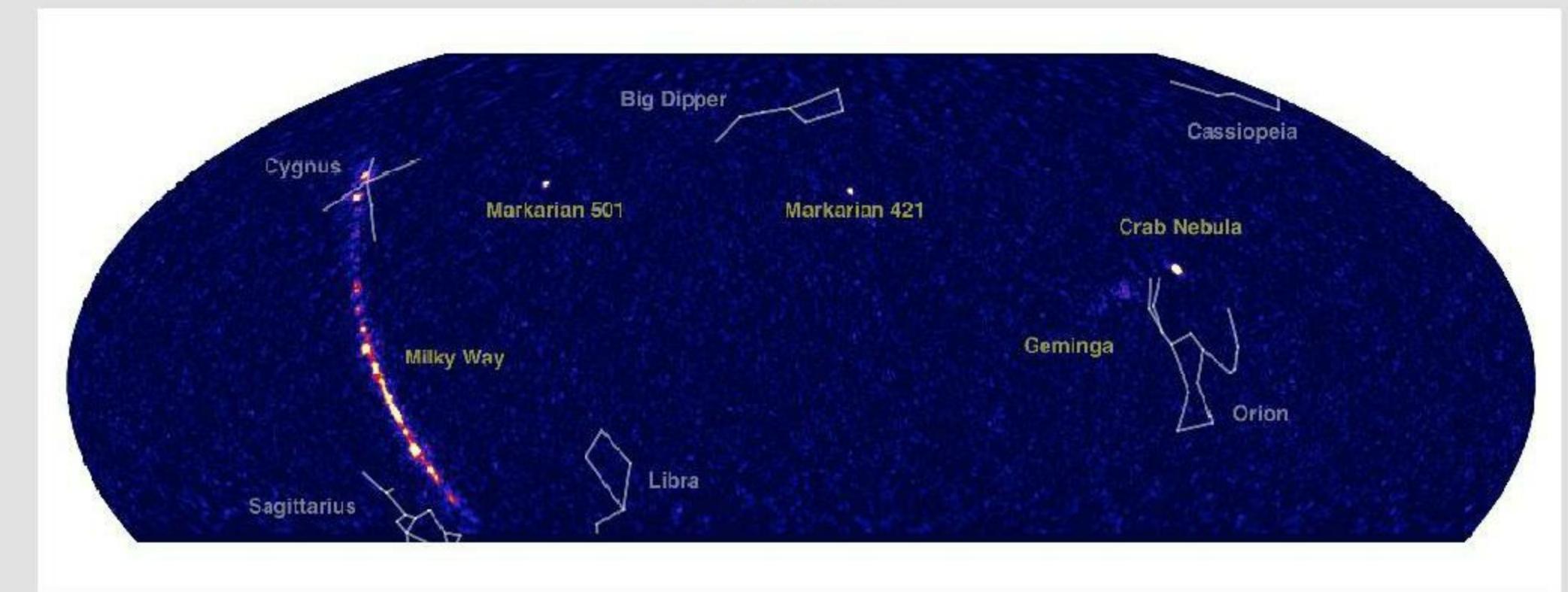
catalogs

Instrument	Point sources	Extended sources
Fermi/LAT	~3000 (3FGL)	~50 (3FGL + FGES)
HAWC (2HWC)	39	(not tested, 9 associations with ext. sources)

Fermi > 1 GeV



HAWC



SYNERGY #1

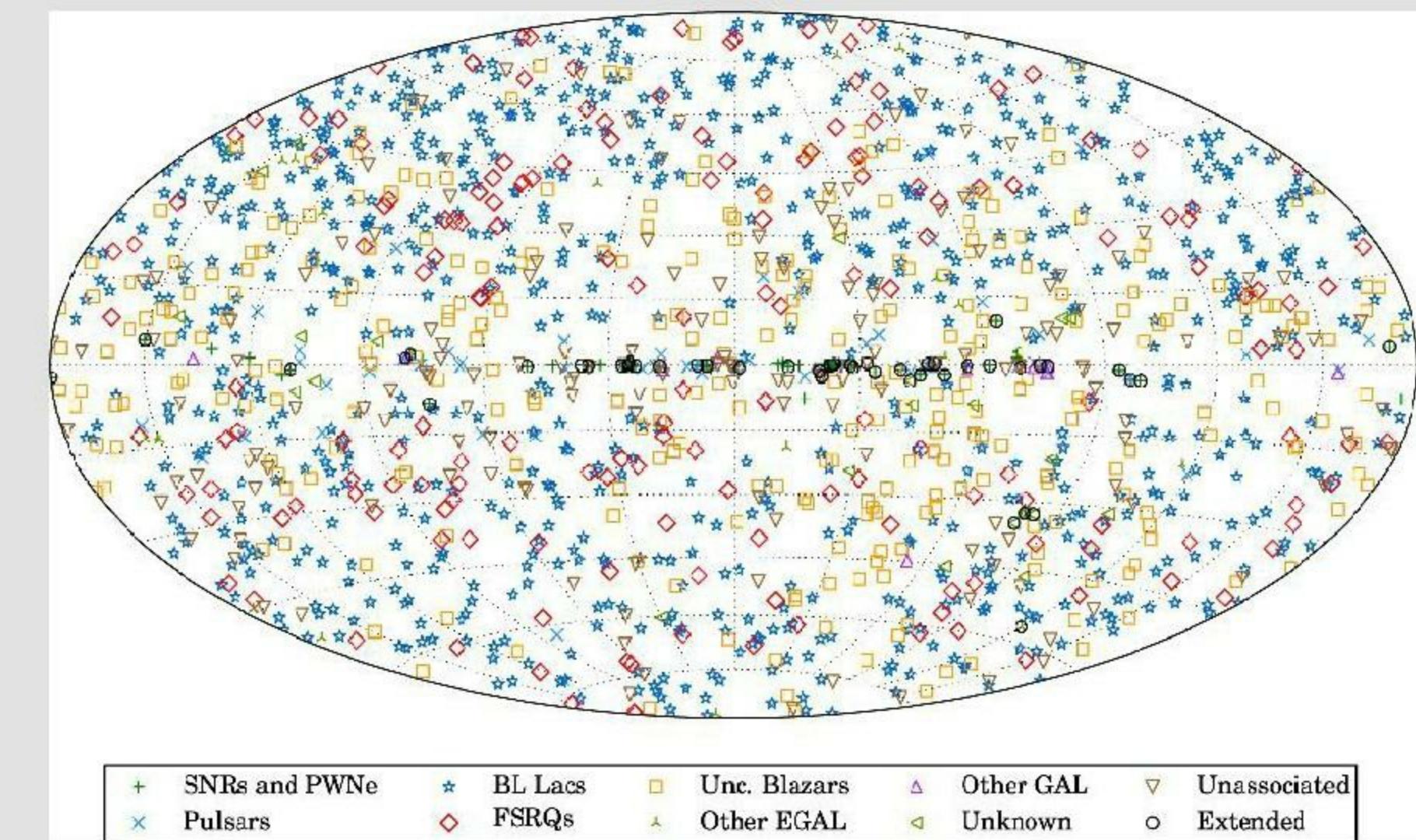
Identification of sources, modeling

- Example:
 - Fermi (and VERITAS) follow up of 14 of the 19 unassoc. sources in 2HWC
 - no counterpart detection from Fermi > 10 GeV
 - no clear association with 3FGL sources
 - 1 counterpart detection from VERITAS
 - VERITAS upper limits deeper than HAWC flux
 - extended sources or spectral shape?

(N. Park et al. TeVPA 2017, J. Hewitt et al. HEAD 2017)

variable sources

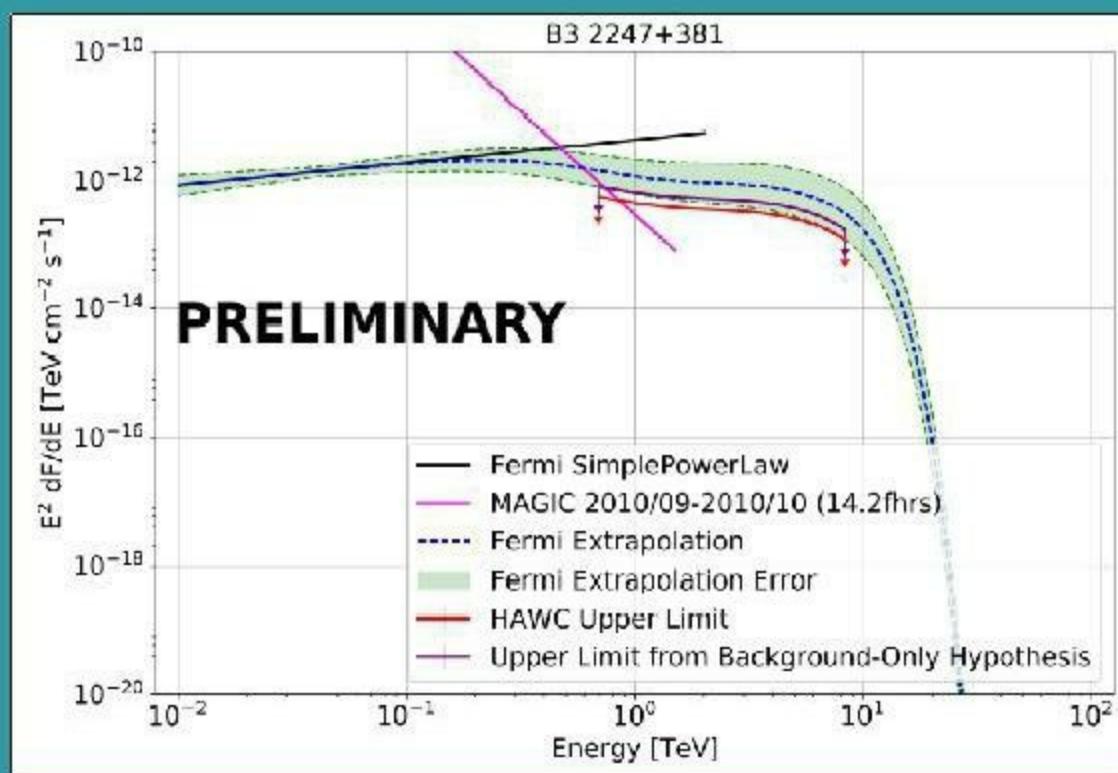
- Majority of Fermi/LAT hard sources (> 1000 3FHL sources) are AGNs
- AGNs at VHE are interesting:
 - physics of acceleration
 - EBL
- Fermi and HAWC can monitor variable sources on time scales from seconds to years
- HAWC detects routinely Mrk 421 and Mkr 501, observes most of the others and can place limits



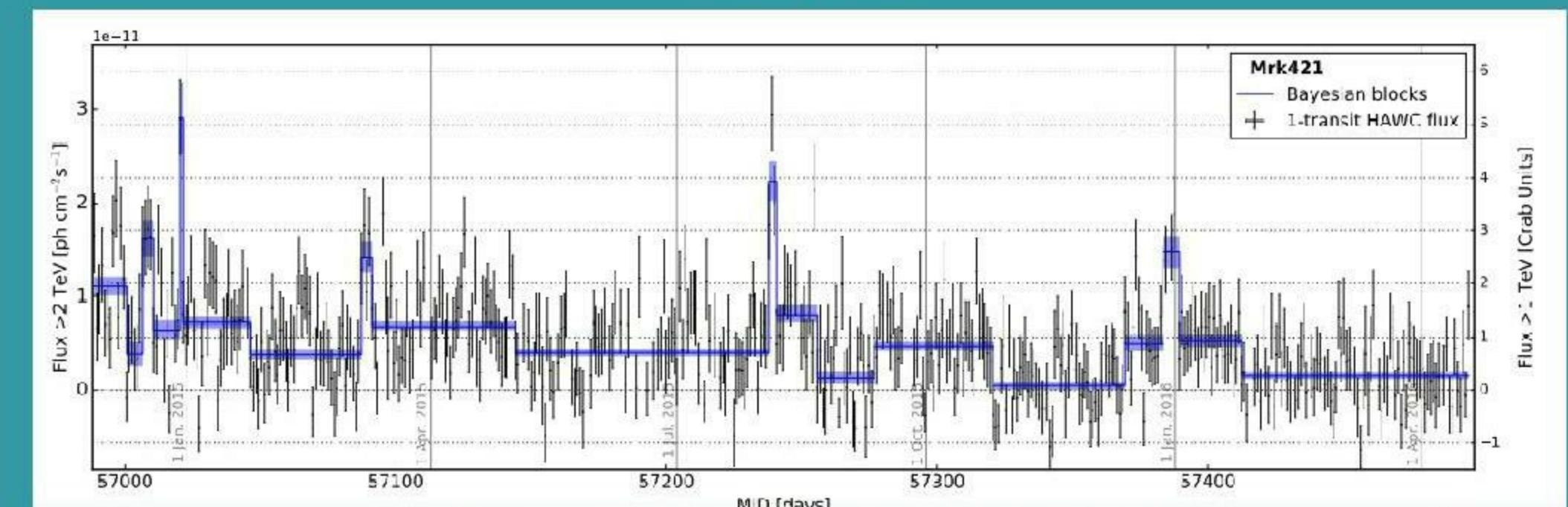
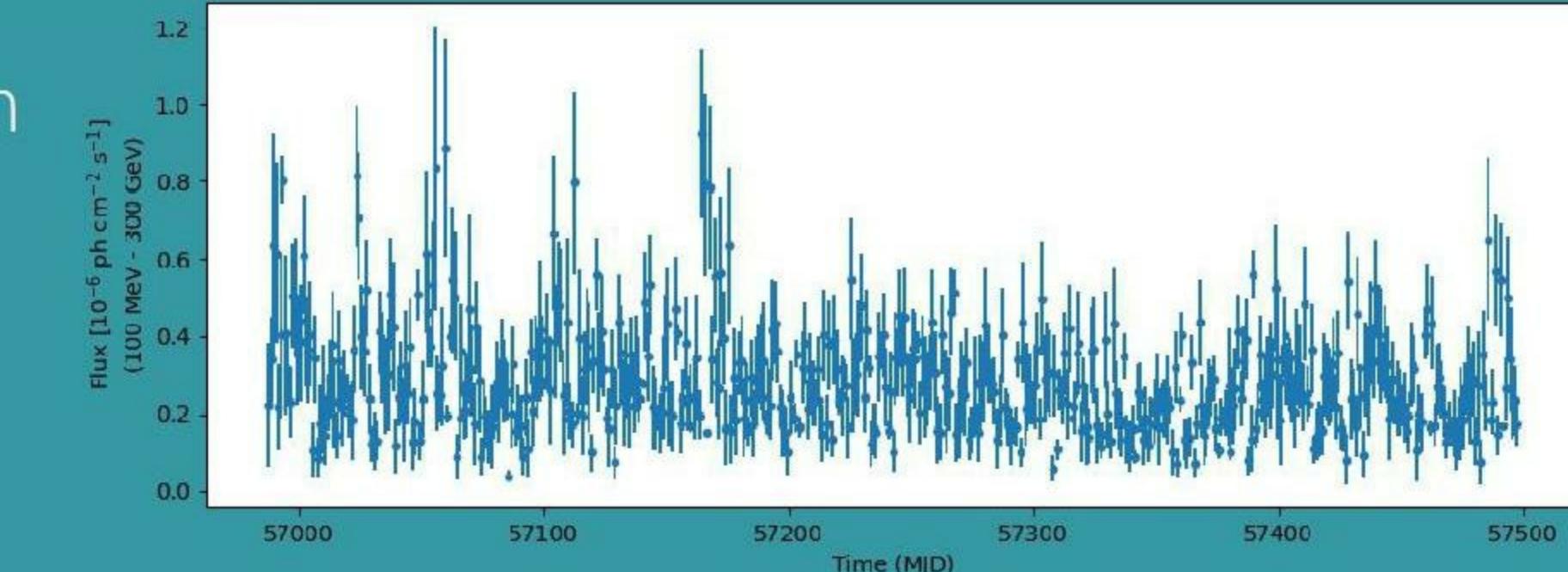
SYNERGY #2

Flares follow up + EBL

- Study of correlated variability in the Fermi and the HAWC energy range
- EBL



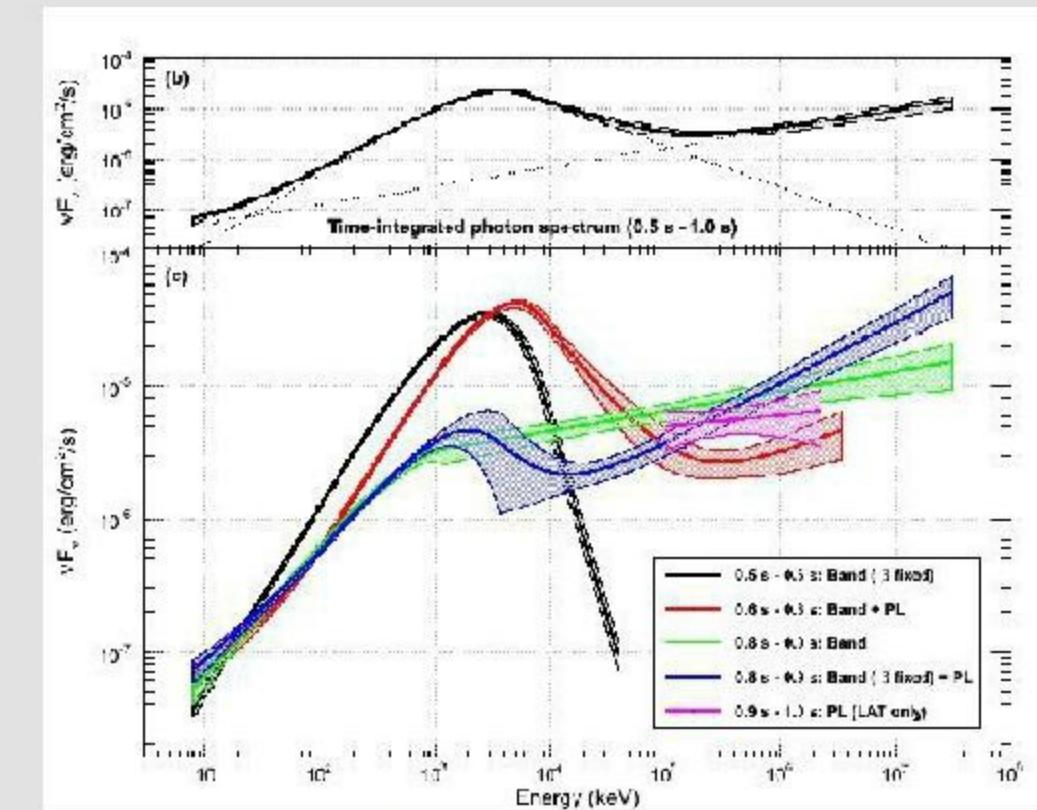
Z.Ren et al. (ICRC 2017)



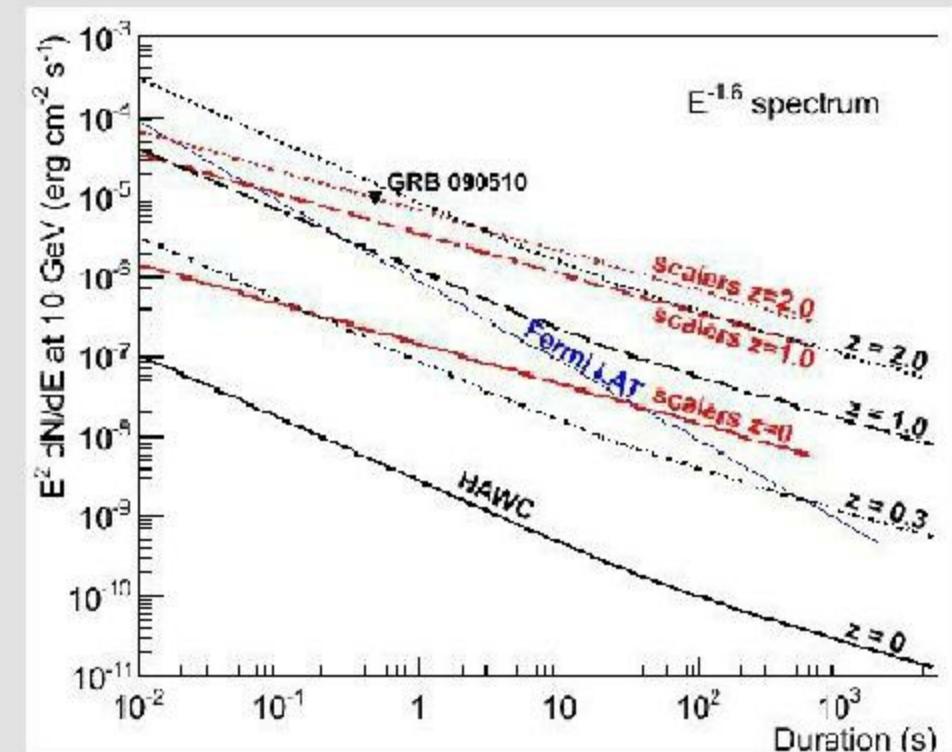
Abeysekara et al. (2017)

Transients: GRBS

- GBM detects ~230 GRBs/y
- Fermi/LAT detects ~15 GRBs/y Some are detected above 10 GeV with hard spectra
- Short GRBs are promising for HAWC
 - short intervals (-> low background)
 - hard spectra
 - lower EBL attenuation (closer)
 - Gravitational Waves...
- ~50 GRBs / year in HAWC FoV, ~5/y short
 - ~3/y with LAT detection (~0.3/y short)
- Tentative detection (3 sigma) by MAGIC of 160821B > 500 GeV



Ackerman et al. 2009

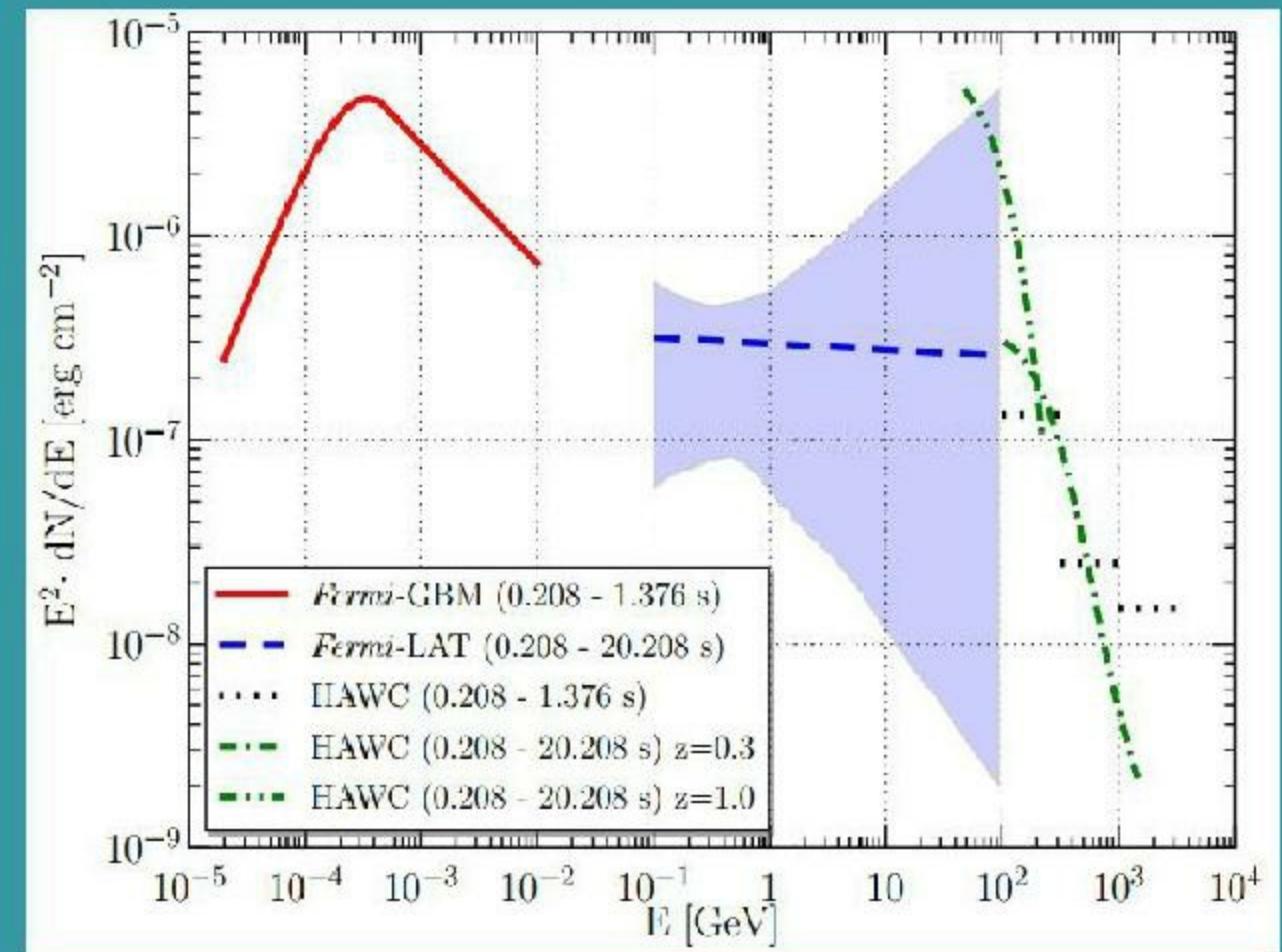


Abeysekara et al.
2011

SYNERGY #3

GRBs

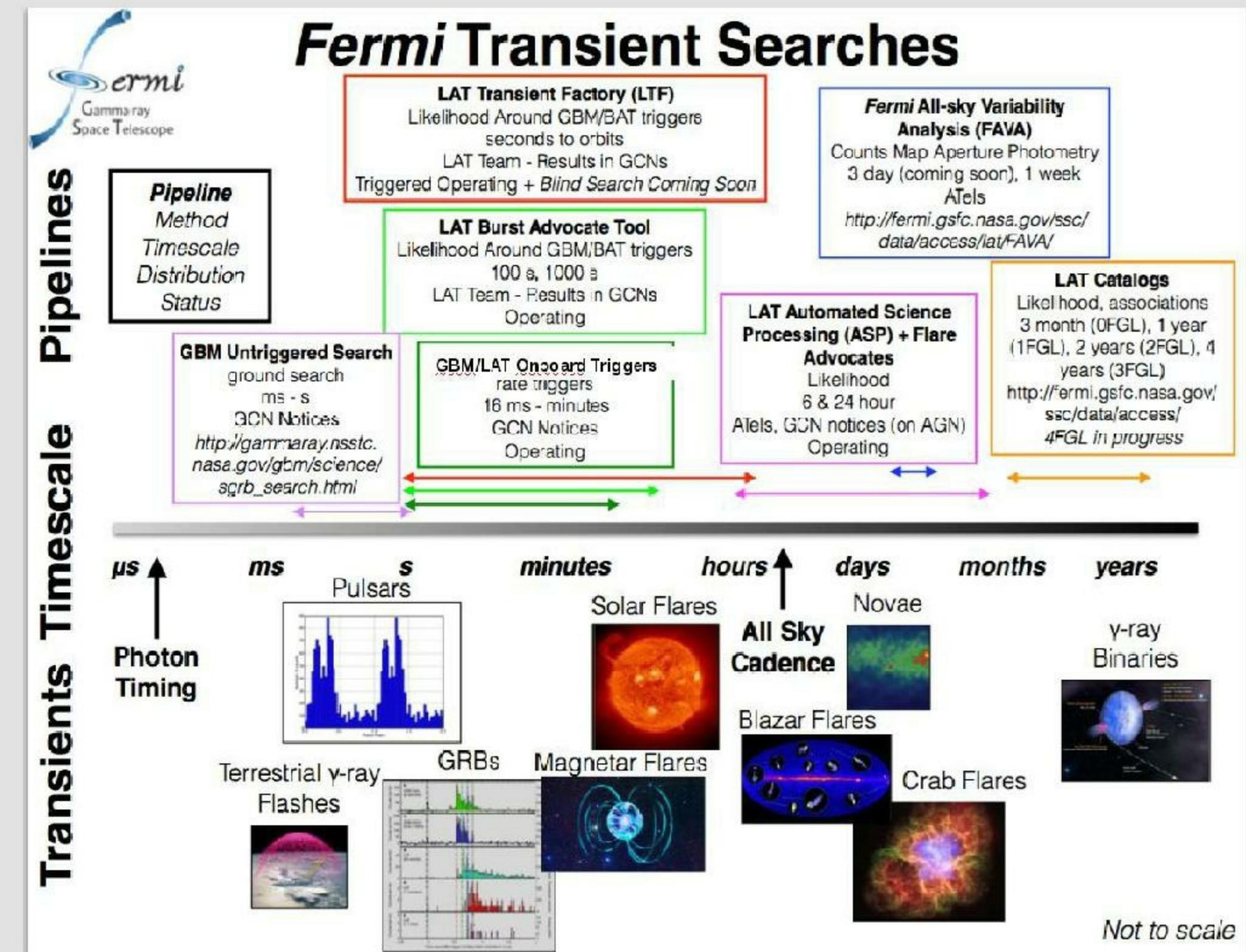
- Example (GRB 170206):
 - short GRB
 - faint in the LAT, but detected
 - HAWC limits start to become interesting
 - there is space for lowering the low-energy threshold for HAWC with ad-hoc analysis



Alfaro et al. 2017

Transients: blind

- Fermi/LAT blind searches:
 - FAVA: 6 hrs, 12 hrs, 1 week
 - LAT Transient Factory: < 6 hours
- HAWC blind searches:
 - < 100 s
- Fermi/GBM searches:
 - on-board on GRB-type time scales
 - on-ground: sub-threshold pipelines



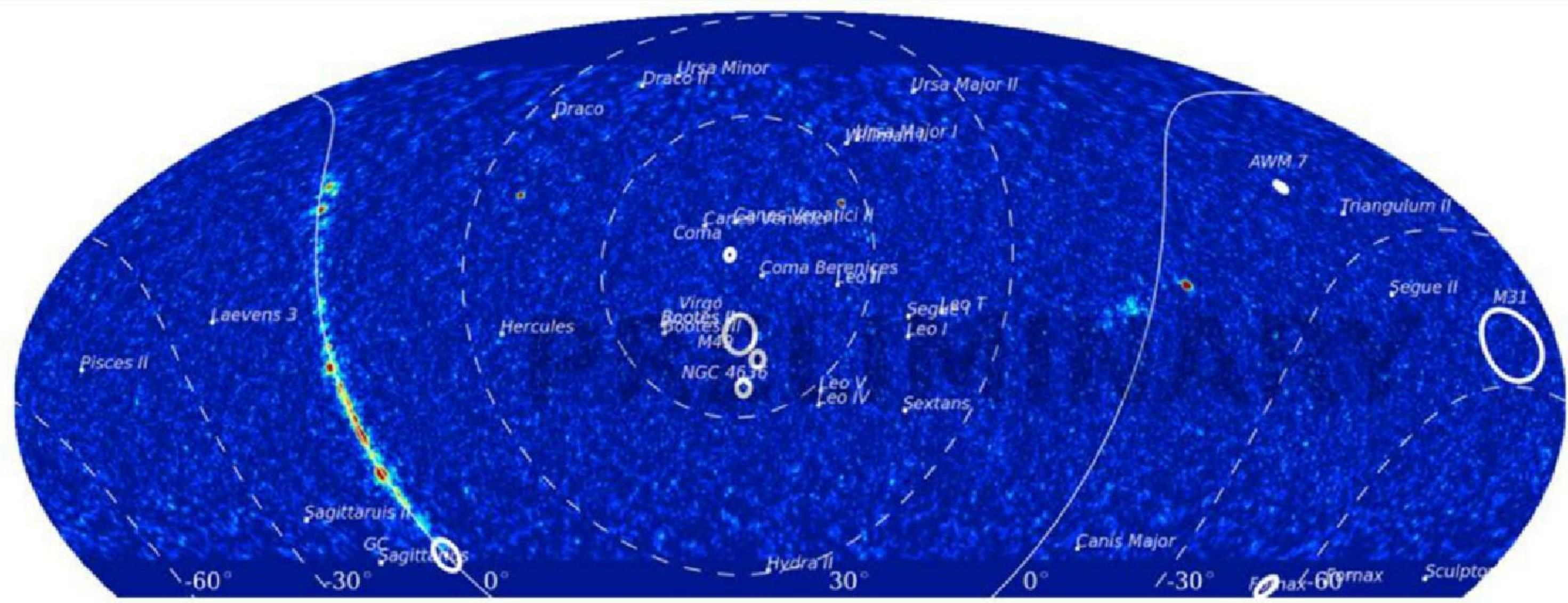
SYNERGY #4

Blind searches for transients

- Fermi/LAT and HAWC are the wide-field, high duty cycle instruments closest in energy
- LAT can follow up on blind searches candidates from HAWC during normal operations, and vice versa
- GBM can look for sub-threshold coincidences



Dark matter



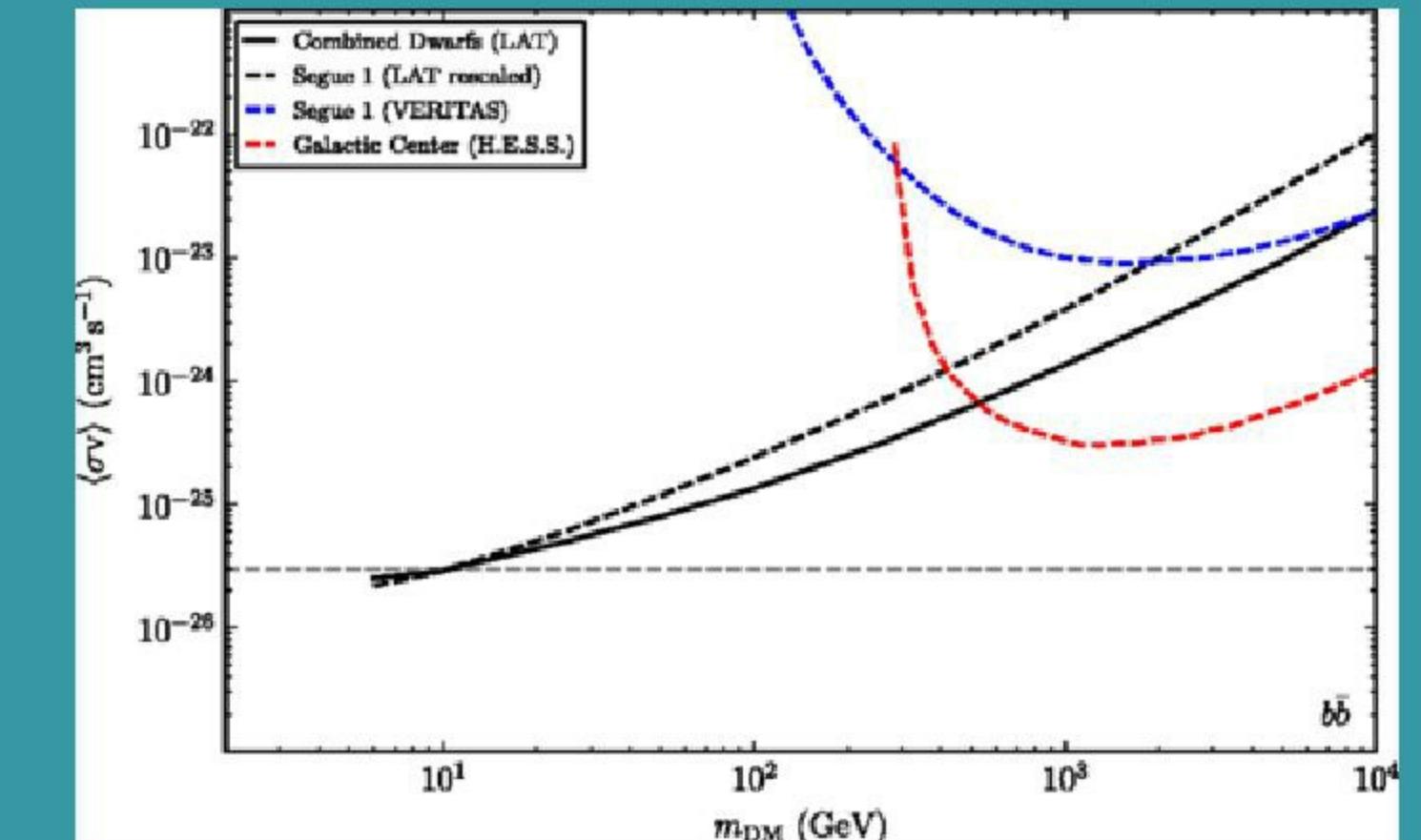
HAWC sky map with dSph galaxies

- HAWC and Fermi/LAT observe many dwarf galaxies around the Milky Way
- DM-rich \rightarrow limits

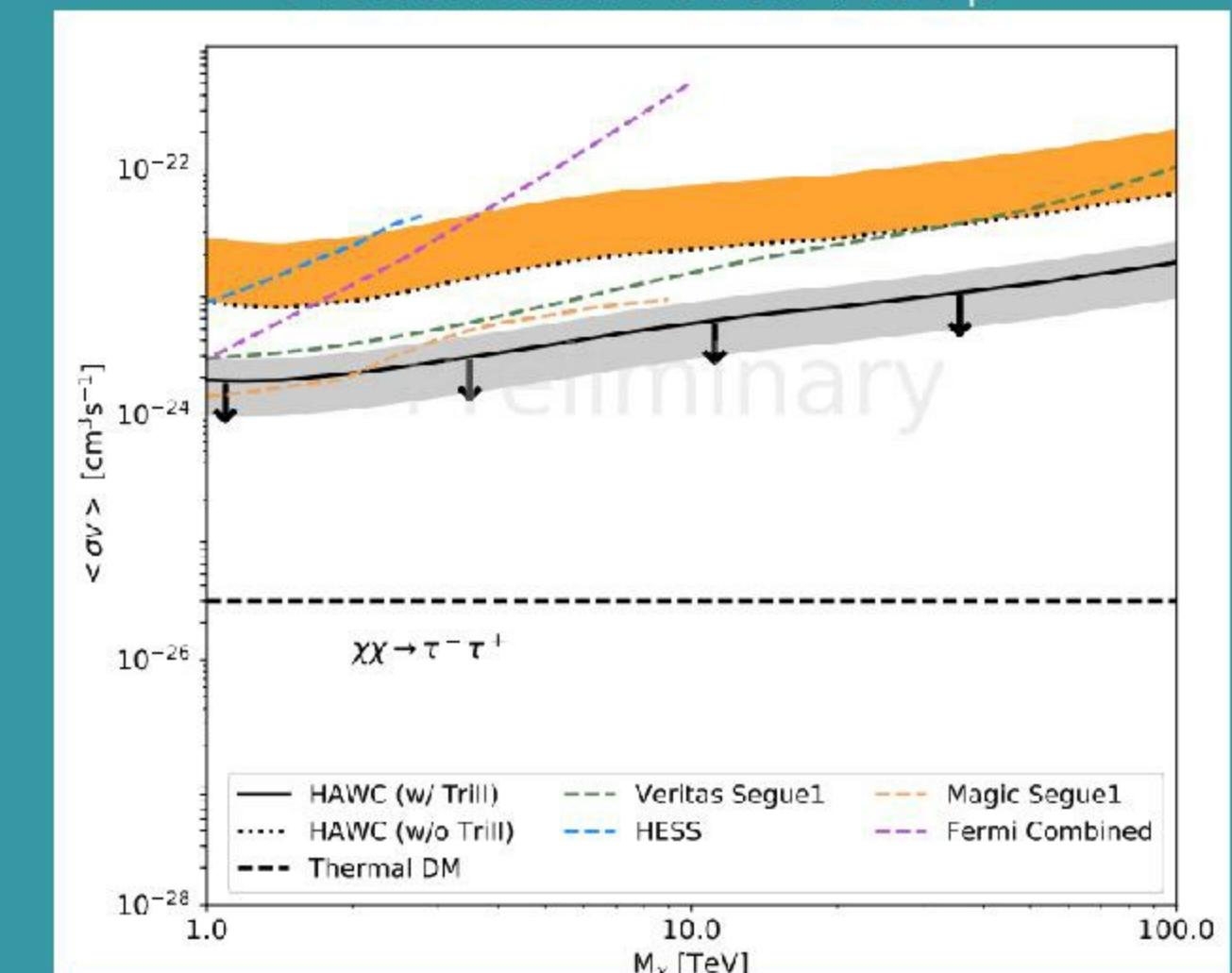
SYNERGY #5

DM limits

- Using Fermi and HAWC it is possible to limit the decay cross section for different channels for DM masses from 10 GeV to 100 TeV



Ackermann et al. (2014)

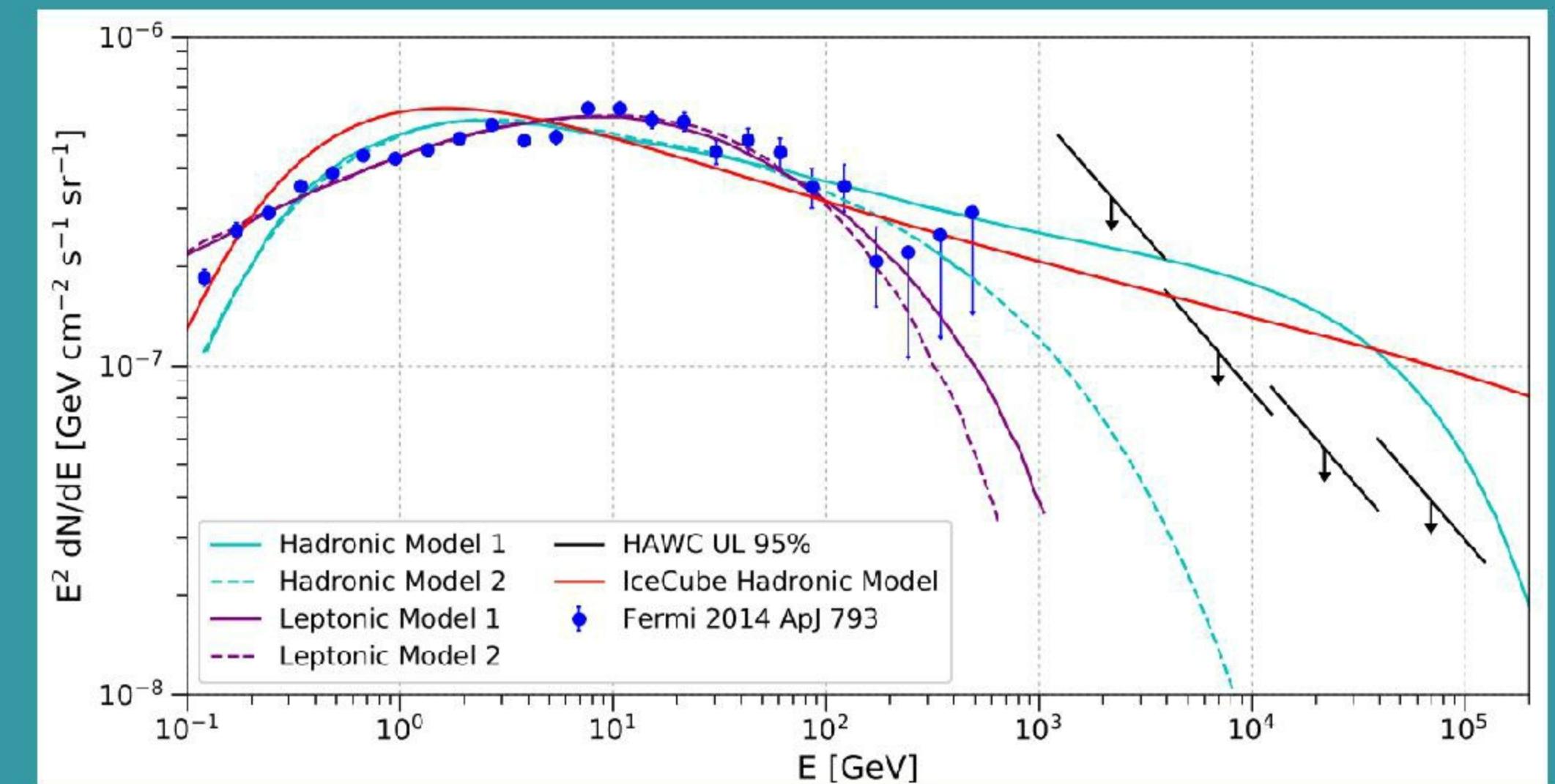


Albert et al. (2017)

SYNERGY # 6

Large structures (bubbles, Galactic diffuse) + CR

- (see Brenda's talk)



Abeysekara et al. 2017

CHALLENGE

Joint analysis



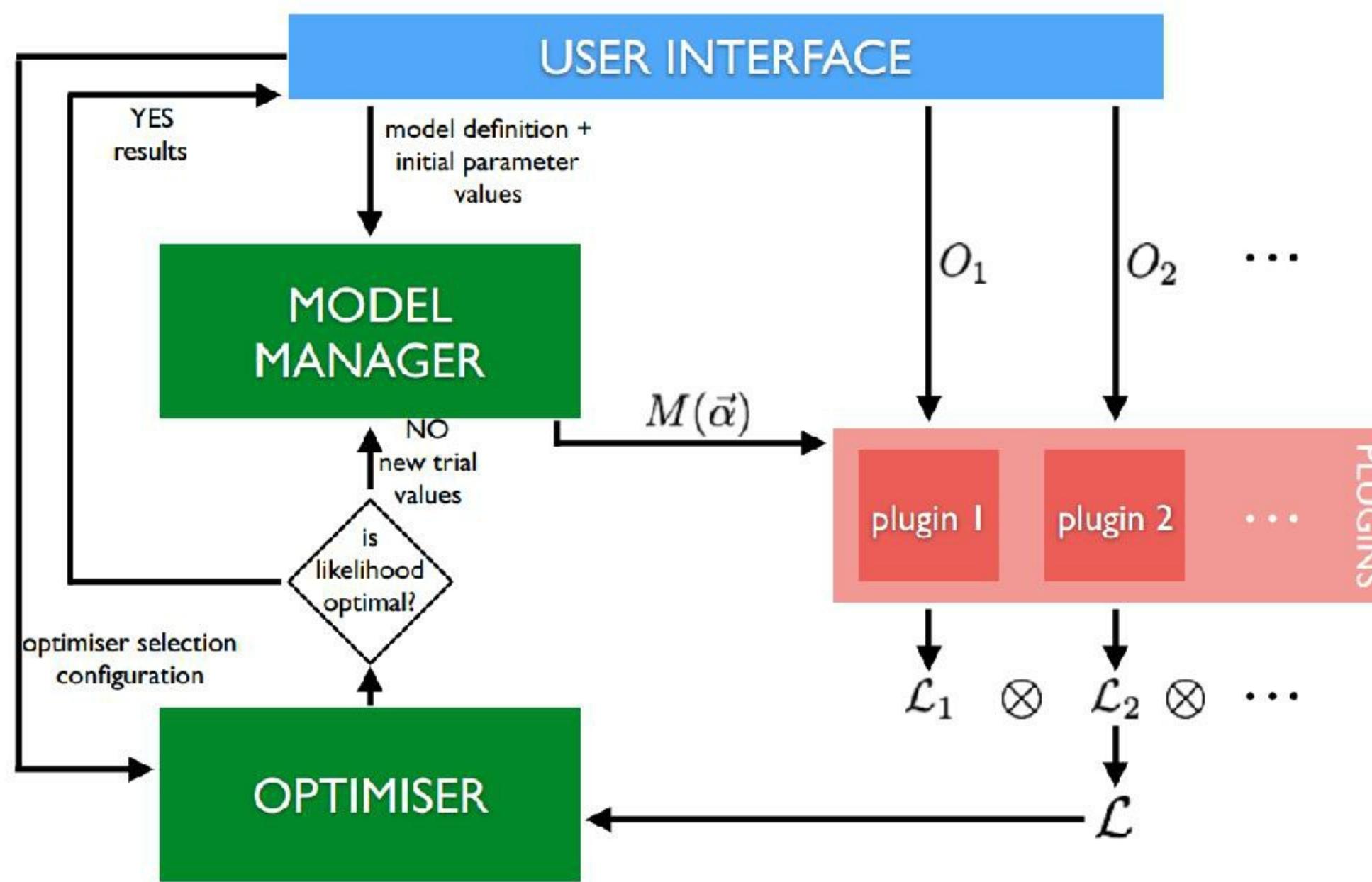
- 1st FVH workshop:
 - likelihood analysis in all experiments
 - however, different data structures, background handling, response modeling
- how can we achieve a joint analysis framework?
 - common analysis software? Difficult... years of development, big changes in established methods, difficult coordinations (who could do this?)
 - how to exploit the work that has been already done?



3ML

The Multi-Mission Maximum Likelihood framework

3ML architecture



- ° based on a joint likelihood approach
- ° model definition and likelihood maximization (or posterior sampling) are handled by 3ML, low-level, instrument-specific likelihood computation by the plugins
- ° exploit existing instrument-specific solutions
- ° allows for future analysis developments beyond the normal forward-folding scheme
- ° analysis from different messengers is possible too (polarization, neutrinos...)

a 3ML analysis

```
# Load some data (these are different plugins)

hawc = HAWCLike(...)
lat = LATLike(...)
swift = OGIPLike(...)

data = DataList(hawc, lat, swift)

# Define model for our data

spectrum_1 = Powerlaw()
source_1 = PointSource("crab", ra=83.63, dec=22.01, spectral_shape=spectrum_1)

spectrum_2 = Powerlaw()
spatial_2 = Gaussian_on_sphere()
source_2 = ExtendedSource("ext", spatial_shape=spatial_2, spectral_shape=spectrum_2)

model = Model(source_1, source_2)

# Prepare likelihood analysis

jl = JointLikelihood(model, data)

# Fit

jl.fit()

# Prepare a bayesian analysis
bs = BayesianAnalysis(model, data)

# Define priors
for parameter in model.free_parameters:

    par = model.free_parameters[parameter]

    par.set_uninformative_prior(UniformPrior)

# Sample the posterior
samples = bs.sample_multinest(live_points=100)
```

CONCLUSIONS



- The best path forward is together
 - multi-wavelength (and multi-messenger) approaches
- Synergies between Fermi and HAWC well established
 - Source identification / modeling
 - Variability
 - EBL
 - Transients
 - Dark matter
 - Cosmic Rays
- Development of joint analysis method (beyond Fermi and HAWC, including Swift, MAGIC, VERITAS, optical telescopes...)